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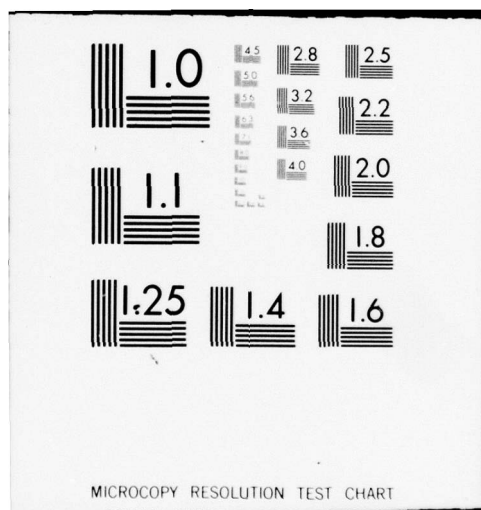APR 79   F J GURNEY   F33615-78-C-5003
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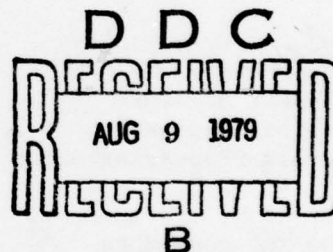FILMED
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A PHENOMENOLOGICAL MECHANISM FOR THE OCCURRENCE OF THE EXTRUSION CENTRAL
BURST DEFECT

Westinghouse Electric Corporation
Advanced Energy Systems Division
Pittsburgh, Pennsylvania 15236

April 1979

TECHNICAL REPORT AFML-TR-79-4031

Interim Technical Report for Period 15 February 1978 - 10 January 1979

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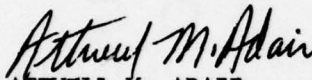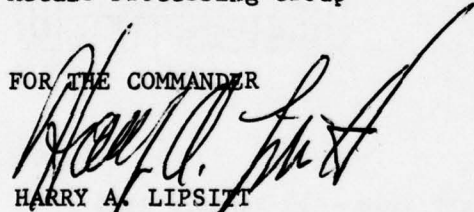
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ATTWELL M. ADAIR
Project Engineer
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FOR THE COMMANDER

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Acting Chief, Processing and
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Six billets of 7075 Al were partially extruded in a horizontal extrusion press using a three-inch diameter container. Extrusion conditions were selected such that the central burst defect would occur. A rigid ram stop mechanism was employed to halt the extrusion process abruptly after selected increments of deformation were achieved in each billet. Both metallographic and scanning electron microscopy analyses were used to identify the mechanism for occurrence of the defect.

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The occurrence of the defect was found to be preceded by the development of tangential velocity discontinuity surface in the deformation zone. Enhanced metal flow in the radial direction on the die exit side of this discontinuity surface caused tensile stresses to develop along the axis of the billet initiating the defect by a tensile overload mechanism. The defect was found to propagate along the discontinuity surface but was halted when continued ram motion caused continued plastic flow along this discontinuity surface to become diffused.

FOREWORD

This report was prepared by the Westinghouse Electric Corporation, Advanced Energy Systems Division, Pittsburgh, Pennsylvania 15236, under USAF Contract No. F33615-78-C-5003. The contract was initiated under Project No. 7351, "Metallic Materials", Task No. 735108, "Processing of Metals", and was administered under the direction of the Metals and Ceramics Division, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio with Mr. A. M. Adair (AFML/LLM) as Project Engineer.

This report covers work performed from 15 February 1978 to 10 January 1979 by F. J. Gurney of the Advanced Energy Systems Division, Westinghouse Electric Corporation. Assistance in the preparation of this report was received from Mr. T. E. Jones, Mr. M. M. Myers and Mr. R. A. Sweeney. The report was edited and typed by Ms. Faye Hickman.

This report was submitted by the author on 18 January 1979.

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SECTION I

INTRODUCTION

Many metal shaping and forming operations for aerospace utilization employ extrusion forging techniques. Production of high strength superalloy bolts and turbine blade preforms are two examples where this forming technique is utilized. The majority of these types of forming operations are performed routinely; however, in some instances a particular combination of material and process variables causes an internal defect to occur in the product which has come to be called central burst.

The occurrence of the central burst defect in drawing and extrusion operations has been reported in the literature for some time[1-21]. The defect is a chevron or arrowhead type opening which occurs along the central region or axis of the deformed product. It frequently occurs as a series of defects with periodic spacing, but it can also occur singly in some forging operations.

The determination of the cause of this defect is of considerable importance because of the losses in material and production associated with its occurrence. Of particular interest are those combinations of material and processing variables which do not in themselves result in the defect, but which just barely avoid the conditions causing the defect. This situation can result in an amount of material damage which is not detectable by ordinary nondestructive techniques but which can cause premature failure in service applications.

While the central burst defect has been examined from both the material and process viewpoint, no systematic analysis of its initiation and development has been reported. Such an analysis is necessary to develop a mechanistic view of the occurrence of this defect so that its prevention can be assured for all processing operations. The effort of this study was directed at this objective. Type 7075 aluminum alloy was used as a model material. Additional follow-on reports will detail the influence of metallurgical and mechanical variables on this defect.

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SECTION II

EXPERIMENTAL PROGRAM

The 7075 aluminum alloy used in this investigation was purchased in the form of a three-inch diameter by twelve-foot long rod. The material was obtained in the T-651 heat treatment and was kept in that condition for machining extrusion billets. The chemical composition of the material is given in Table I.

The extrusion program was conducted at the Experimental Metals Processing Laboratory at Wright Patterson Air Force Base, Ohio. A 700 ton $(6.23 \times 10^6 N)$ horizontal accumulator type extrusion press manufactured by Lombard Corporation was used in this program. The hydraulic media was water-water soluble oil and the operating pressure was 3050 psi (21.0 KPa). The admission of pressurized fluid to the press chamber was controlled through use of a hydraulic valve to allow ram velocities between 0.5 ips $(6.25 \times 10^{-2} ms^{-1})$ and 10.0 ips $(25.4 \times 10^{-2} ms^{-1})$. The press container was 3.062 in. $(7.78 \times 10^{-2} m)$ diameter by 15 in. (0.381m) long and was heated by electric resistance cartridge type heaters so that a temperature between ambient and 800°F (700°K) could be obtained. The extrusion press was instrumented so that the stem load, ram position and ram velocity were monitored and recorded through use of a Honeywell 1508 Visicorder.

The standard extrusion billets used in this program were three-inch diameter and five and one-half inches long. A die-entry chamfer was machined on one end of the billet. The chamfer was at a 45° angle over an axial length of one-half inch.

The extrusions performed in this program were partial extrusions in which a portion of the original billet was left in the container. A rigid stop of the extrusion process was obtained through use of a ram stop ring which upon contact with the container allowed all of the press energy to be dissipated through the container. This technique allowed the extrusion process to be stopped almost instantaneously regardless of the ram velocity. This process is illustrated in Fig. 1. Varying lengths of partial extrusions were obtained by use of a series of dummy blocks whose lengths were varied from 1-1/2 in. $(3.81 \times 10^{-2} m)$ to 3-1/2 in. $(8.89 \times 10^{-2} m)$ in increments of 1/8 in. $(3.18 \times 10^{-4} m)$. Lengths between these 1/8 in. $(3.18 \times 10^{-4} m)$ increments were obtained by use of shim stock spacers bonded to the backs of dummy blocks.

An initial small trial extrusion program was performed to bracket the conditions where the central burst would and would not occur. From this effort, a base-line set of variables was selected to be: billet temperature 300°F (422°K) with a two hour heating time; die geometry of 4:1 reduction ratio with a 90° conical angle and a smooth bearing surface; ram velocity of 1.5 ips $(3.81 \times 10^{-2} ms^{-1})$; lubrication for the container to be Fiske 604

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hot die lubricant applied just prior to extrusion and lubrication for the
billet to be Fel Pro C-300 applied prior to heating. A series of partial
extrusions based on the standard set of variables was performed using
incremental lengths of dummy blocks. After completion of the desired de-
formation process, the partial extrusions were removed from the press and
sectioned to show the deformed structure.

The metal flow and fracture morphology associated with the development
of the defect were examined by standard metallographic techniques and by
scanning electron microscopy. An ETEC scanning electron microprobe equipped
with a KEVEX energy dispersive analyzer was used.

SECTION III

RESULTS

The results from the use of the rigid ram stop process employed for a
series of six billets are shown in Fig. 2. These results show the incremental
variations in the initiation and growth of the defect. Data for these billets
are given in Table II.

These results illustrate the variations in metal flow which cause the
central burst defect to develop. Prior to the occurrence of a burst, a
surface develops in the deformation zone along which metal flow localizes. A
three-dimensional view of this surface would yield a circular cone with a
slightly concave surface. Enhanced metal flow tends to be promoted along this
surface as the extrusion process continues. The burst initiates along the
billet axis at the apex of this conical surface of localized flow. The
fracture propagates along the cone surface as the surface is pushed toward the
die by the continuing ram motion. After the fracture has moved a certain
distance through the die, a new surface of localized flow develops in the
deformation zone and the entire process is repeated.

The ram load and ram velocity recorded during an extrusion in which
central bursts occur are shown schematically in Fig. 3. The ram load rises
to a peak condition, but then drops sharply. This rapid drop in load is
accompanied by a rapid peaking in the ram velocity and signifies the
occurrence of the first burst in the product. After the rapid load drop,
the load again builds up as the extrusion process continues until a load is
reached which is approximately equal to or slightly higher than the steady
state load of a sound extrusion. The load then drops again, although not as
rapidly as the initial drop, until the approximate same minimum load at which
point another burst occurs. The process continues in a cyclic manner. The
ram velocity peaks at each minimum in the load where the bursts occur.

Metallographic examination of the defect at various stages during its
development reveals more detail about its origin and propagation. The con-
figuration of the defect and adjacent material shown in Fig. 4 is from an
extrusion which was halted just after the defect initiated. A considerable
number of voids opening around the inclusion stringers can be seen. Exami-
nation of the defect cone shows that the crack propagation occurs in jogged
steps where voids develop along the inclusion stringers.

The shape of the defect shown in Fig. 5 is from an extrusion which was
halted after the defect cone was about one-half developed. The concentration
of metal flow at the crack tip is seen to be considerably enhanced over that
nearer the cone tip shown in Fig. 3. The propagation path is also more
defined and almost no secondary defects can be seen adjacent to the principal
fracture.

The portion of the defect shown in Fig. 6 is from an extrusion which was halted as the cone was almost two-thirds developed. The striking feature illustrated in this figure is that the crack tip has become blunted. The material ahead of the crack tip, however, shows intense shear indicating a large amount of plastic deformation over a rather large band. A type of turbulent flow occurs forming the toroidal surface noted at the base of the central burst cone in Fig. 2. The terminal stage of the crack propagation is shown in Fig. 7 which is a section of an earlier burst which had passed completely through the process.

The general shape of the central burst cone examined by scanning electron microscopy is shown in Fig. 8. The included angle of the cone approximates 90° near the tip, but becomes larger at greater distances from the tip. A very small flat region is sometimes found at the cone tip, where fracture initiates.

The fracture morphology at the crack tip, Fig. 9, leaves no doubt that a tensile overload failure occurs at the tip of the cone. The fracture morphology at the tip shows deep voids with second-phase particles visible in many of the voids. The voids appear to have grown until the ligaments between them necked to zero area leaving a network of rather sharp ridges indicative of ductile rupture. The walls of the voids are relatively smooth, but show a considerable amount of beach-sand ripples. Some smaller voids are observable along the ripples which connect the voids. The beach-sand ripples along the void walls are more apparent in Fig. 10. The second-phase particles visible in the voids were found to be enriched in iron and copper. The region near the cone tip, shows the sand-beach ripples between rather deep voids.

The shear region along the conical surface of the central burst cone is shown in Fig. 11. The elongated parabolic dimples of the larger voids are clearly evident. Some smaller secondary dimples can be seen in larger voids. A considerable amount of copper-iron inclusion debris can be seen in the valleys of the large parabolic dimples.

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SECTION IV

DISCUSSION

Examination of the series of partially extruded billets, Fig. 2, clearly shows that the activation of a tangential velocity discontinuity and the localization of shear along the discontinuity are prerequisites to the development of the central burst defect. This sequence of billets allows a phenomenological mechanism for the defect to be suggested. The mechanism is illustrated schematically in Fig. 12. The tangential velocity discontinuity causes increased material flow toward the billet axis on the die exit side of the discontinuity resulting in a type of radial compression at the axis. Since the material is essentially incompressible, the increased radial flow toward the axis must be accommodated by increased axial flow along the axis in the direction of the die exit. A large differential of metal flow must then exit along the axis between the material immediately ahead and immediately behind the discontinuity. This causes large tensile stresses along the axis of the billet. When these stresses reach the tensile strength of the material under the imposed conditions, tensile overload fracture occurs in a small core region at the billet axis.

Initially after localized flow occurs, it is energetically favorable for flow to continue at the localized band because of the associated thermal softening. Continued flow along the shear instability band causes the propagation of the defect. In the case of extrusion, the ram motion continues to move the remaining billet through the die so that localized flow in that band is no longer favorable thereby halting the propagation of the defect. The flow field then becomes readjusted and the process begins again.

This mechanism for the central burst defect conforms with basic mechanics of ductile fracture involving shear instabilities[22,23] and tensile stresses[23-25]. It also conforms with prior observations and studies of this defect based on a requirement of tensile stresses[10]. The proposed mechanism argues that an enhancement of tensile stresses occurs at a small core region along the axis of the billet so that values equal to those deduced for tensile fracture seem plausible. The fact that tensile stresses initiate the defect is verified by fractography at the cone tip, Fig. 9. Further verification that axial tensile forces exist at the initiation of the defect can be deduced by the rapid opening of the defect tip as the fracture propagates along the discontinuity band.

The fact that straining becomes localized indicates a type of plane strain flow occurs. Such flow is not compatible with an axisymmetric process; however, it may occur on the cone wall for a short period where the material flow down the cone is translated to axial flow simultaneous with the propagation of the defect along the cone wall. Such flow would suggest that

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the discontinuity planes are planes of maximum shear as opposed to planes of pure shear which seem to occur in instabilities with sheet tensile specimens[22].

These arguments suggest that more detailed information could be obtained from an analysis of plastic instabilities, particularly the gradient of shear stress within the workpiece as the planes of maximum shear are approached in the deformation zone. Seemingly, conditions of sharp gradients would promote localized flow while conditions of gradual gradients would allow diffuse flow. It would also be of interest to determine the effective strain at which the maximum stress occurs. If this strain corresponds to the zero or negative slope condition of the true stress-true strain relation for the material at the test conditions, then further enforcement of the condition for localized flow would be achieved.

These arguments further suggest an explanation for the difficulties of mathematical formulations in predicting the occurrence of this defect. The common assumption in mathematical analyses is that a metal flow field becomes established and continues in the same way. The analyses assume either rigid plastic or continuously hardening material. No known analysis exists which is based on real material stress-strain behavior for the regions of high strain and high strain rate where deformation softening occurs. The strain at the onset of deformation softening in real materials seems likely to be influential in the development of the shear instabilities which this research shows leads to the central burst defect. These areas will be examined in more detail in subsequent reports.
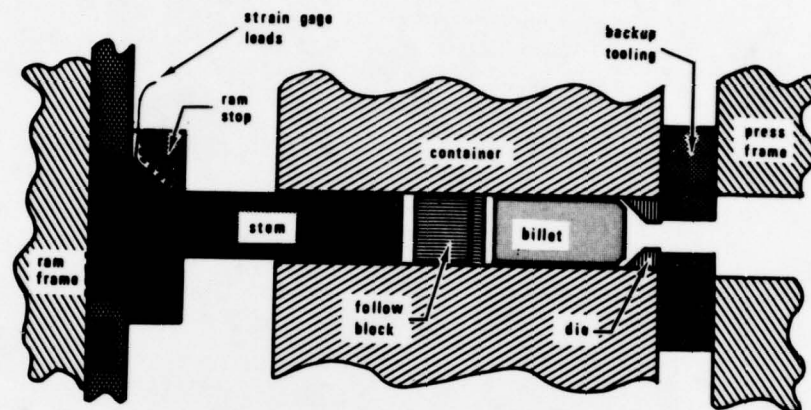
SECTION V

CONCLUSIONS

The results of this investigation of extruded 7075 aluminum alloy establish the mechanism for the central burst defect.

1. The occurrence of a tangential velocity discontinuity band in the metal deformation zone and the localization of metal flow along the band are events which precede the occurrence of the central burst defect.

2. Fractographic evidence from scanning electron microscopy analyses of the central region of fractured tensile specimens and the tip of the burst cone confirm that the central burst defect is initiated by a tensile overload mechanism. An enhancement of axial tensile forces in extrusion occurs by the translation of radial metal flow on the die exit side of the discontinuity band to increased axial flow along the central core region of the billet.

3. Deformation softening in the shear instability band favors continued localized plastic flow causing the defect to propagate along the band. Continued ram motion causes the instability surface to be moved toward the die exit diffusing the instability band and halting the defect growth.

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REFERENCES

1. Harris, F. W., "Distribution of Tensile Strength in Hard Drawn Copper Wire", Trans. AIME, IMD, 1928, p. 518.

2. Jennison, H. C., "Certain Types of Defects in Copper Wire Caused by Improper Dies and Drawing Practice", Trans. AIME, IMD, 1930, p. 121.

3. Tanaka, H., "On the Causes of Cuppy Defects in a Drawn Material", Journal of Japanese Institute of Metals, 16, 1952.

4. Remmer, W. E., "Causes of Cuppy Wire", Transactions AIME, IMD, 1930, p. 107.

5. Rogers, H. C., "Fracture Initiation and Propagation During Strip Drawing", in Advances in Research on the Strength and Fracture of Materials, Vol. 2A, Ed., D. M. R. Taplin, Pergamon Press, New York, 1978, p. 435.

6. Blickwede, D. J., "Cold Extruding Steel", Metals Progress, 97, No. 5, 1970, p. 76.

7. Russell, J. V., "Steels for Cold Forming", Metals Engineering Quarterly, 2, February 1962, p. 49.

8. Zimerman, Z., and B. Avitzur, "Analysis of the Effect of Strain Hardening on Central Bursting Defects in Drawing and Extrusion", TRANS. ASME, Journal of Engineering for Industry, Series B, 92, February 1970, p. 135.

9. Zimerman, Z., H. Darlington and E. H. Kottcamp, Jr., "Selection of Operating Parameters to Prevent Central Bursting During Cold Extrusion", in Metal Forming: Interrelation Between Theory and Practice, ed., A. L. Hoffmanner, Plenum Press, New York, 1971, p. 47.

10. Latham, D. J. and M. G. Cockcroft, "The Effect of Stress System on the Workability of Metals", National Engineering Laboratory, Report No. 216, East Kilbridge, Glasgow, U. K., February 1966.

11. Rice, W. B., and J. N. Gardner, "Similarities in Mechanics of Extrusion and Continuous Chip Formation", in Proceeding, 6th North American Metalworking Research Conference Proceedings NAMRC, April , 1968, p. 185.

12. Pepe, J. J., "Central Burst Formation During Hydrostatic Extrusion", Metal Engineering Quarterly, 16, (1), February 1976, p. 46.

13. Cruden, A. K., "The Effect on the Extrusion of Steel of a Prior Extrusion Operation", National Engineering Laboratory Report No. 341, East Kilbridge, Glasgow, U. K., 1968, (Reference No. 31 of Cockcroft, Ref. 21 below).

14. Kalpakjian, S., "Chevron Fracture in Tube Reduction by Spinning", in Advances in Research on the Strength and Fracture of Materials, Vol. 2A, Ed., D. M. R. Taplin, Pergamon Press, New York, 1978.

15. See written discussions of Remmers' paper on pp. 116-120 of Transactions AIME, IMD, 1930, and of Jennisons' paper on pp. 132-139 of Trans. AIME, IMD, 1930.

16. Miki, T., T. Tamano and S. Yanagimoto, "Factors Causing Internal Cracks in Multi-Stage Extrusion", in Proceedings, 6th North American Metal-working Research Conference Proceedings NAMRC, April, 1968, p. 185.

17. Avitzur, B., Metal Forming: Processes and Analysis, McGraw-Hill, New York, 1968.

18. Avitzur, "Study of Flow Through Conical Converging Dies", in Metal Forming: Interrelation Between Theory and Practice, Ed. A. L. Hoffmanner, Plenum Press, New York, 1971, p. 1.

19. Zimerman, Z. and B. Avitzur, "Metal Flow Through Conical Converging Die - A Lower Upper Bound Approach Using Generalized Boundaries of the Plastic Zone", TRANS. ASME, Journal of Engineering for Industry, Series B, 1970, p. 119.

20. Gurney, F. J. and V. DePierre, "The Influence of the Interface Condition on the Plastic Deformation Zone and the Resultant Product Integrity in Extrusion", Journal of Engineering for Industry, TRANS. ASME, 1974, 96, Series B, (3), pp. 912-916.

21. Cockcroft, M. G., "Ductile Fracture in Cold Working Operations", in Ductility, American Society for Metals, 1968.

22. Spretnak, J. W., "Formulation of the Limiting Ductility in Metalworking Processes", Air Force Materials Laboratory Technical Report, AFML-TR-74-160, August 1974.

23. Backofen, W. A., Deformation Processing, Addison-Wesley Publishing Company, Reading, Massachusetts, 1972, p. 199.

24. McLean D., Mechanical Properties of Metals, John Wiley and Sons, New York, 1962, p. 236.

25. Oh, S. I. and S. Kobayashi, "Deformation Mode of Void-Growth and Coalescence in the Process of Ductile Fracture", AFML-TR-75-95, July 1975.

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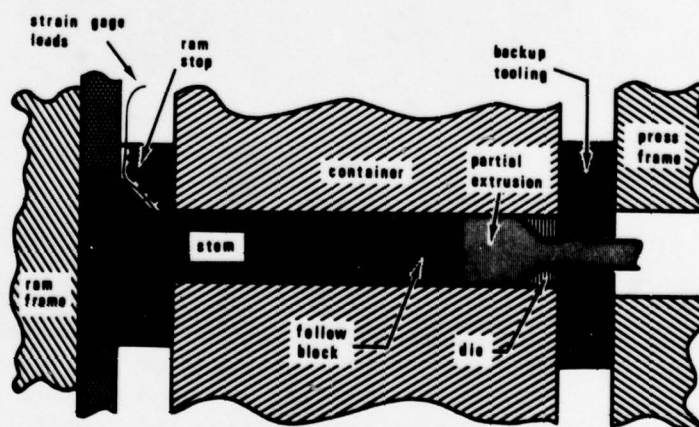
RIGID STOP YIELDING A PARTIAL EXTRUSION

Fig. 1.   Illustration of the rigid ram stop used for
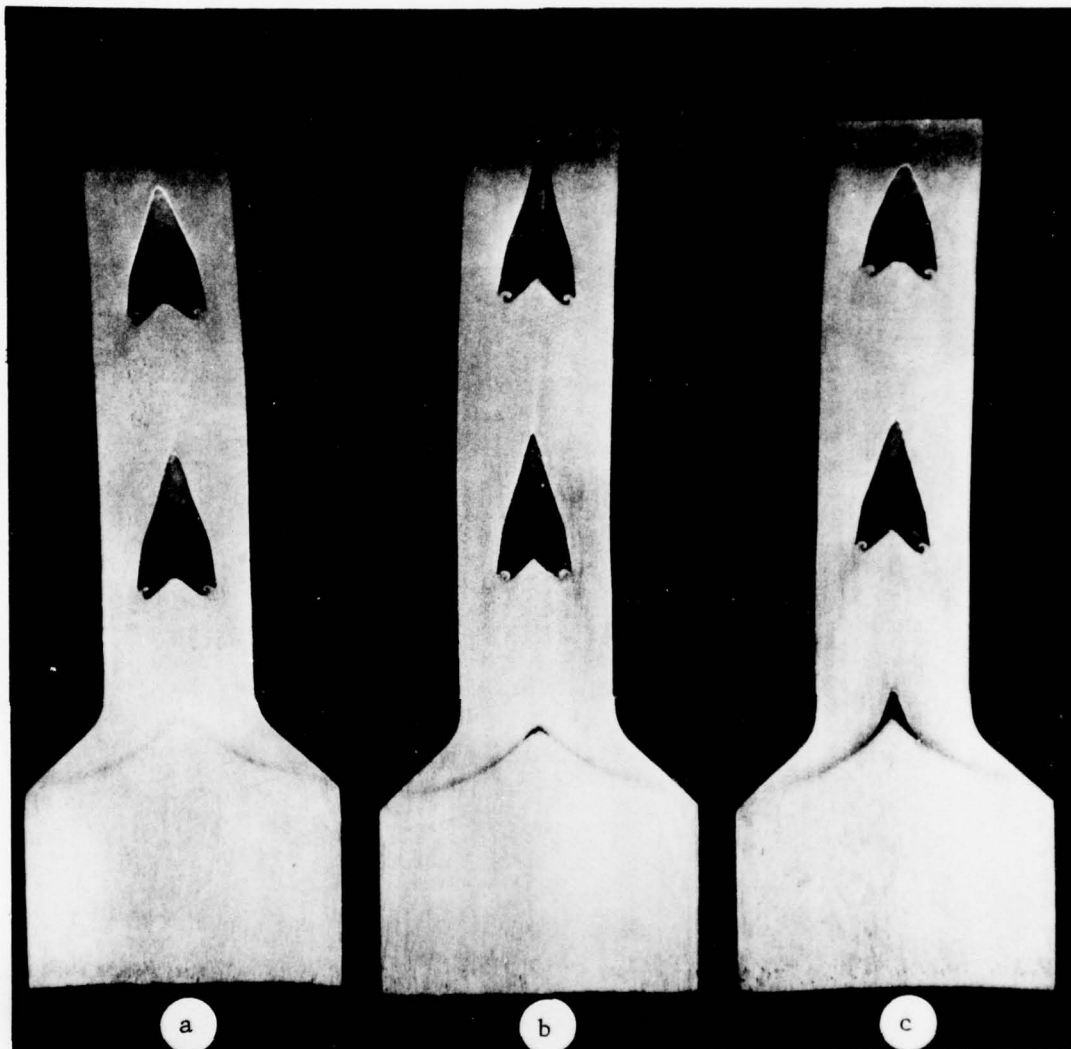the partial extrusions.

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Fig. 2a.   Macrographs of a sequence of longitudinally sectioned partially extruded billets showing the development, propagation and repetition of the central burst defect. The above sequence shows a) the development of the tangential velocity discontinuity surface, b) the initiation of the burst at the axial center of the billet at the tip of the discontinuity surface and c) the rapid opening of the defect.
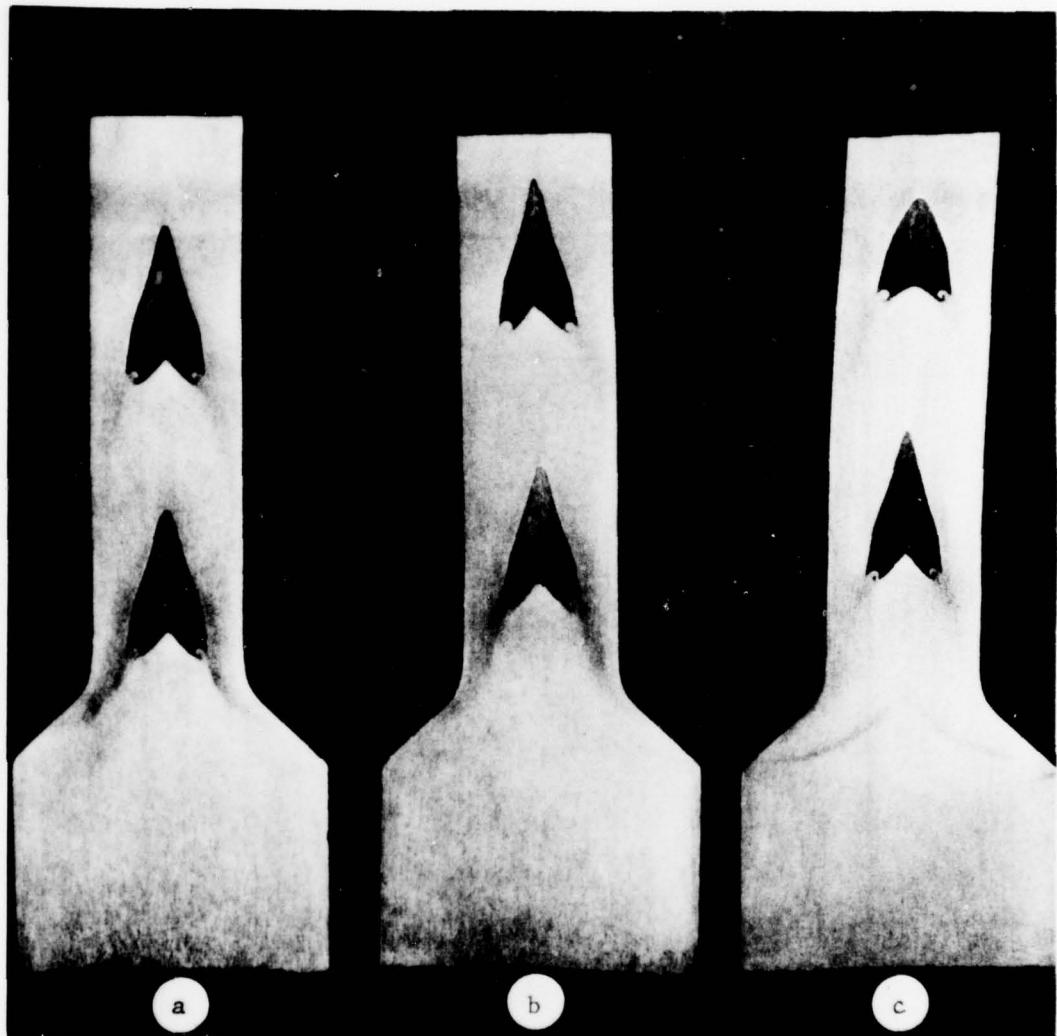
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Fig. 2b. The above sequence shows a) the fully
developed defect exiting the die with
metal flow concentrated at the outer
shell of the product followed by b) the
re-establishment of the metal flow within
the die cone and the initiation of a new
tangential discontinuity surface beginning
at the outer portion of the billet where
the initial entry to the die cone occurs
and c) the continued development of the
discontinuity with concentrated flow in
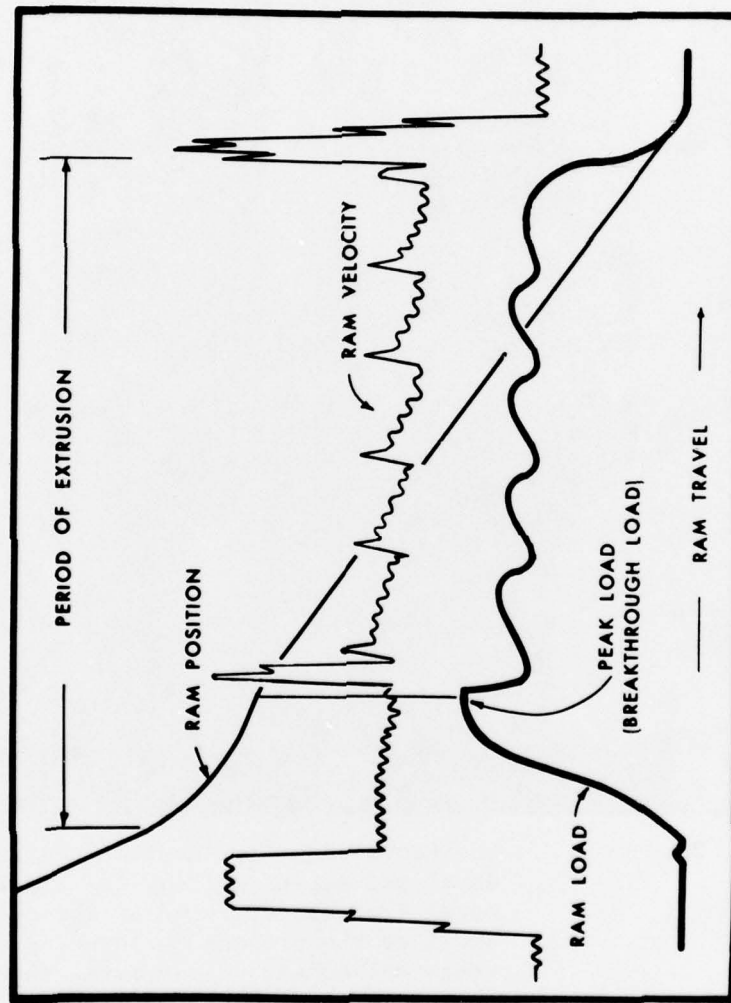preparation for the next burst.

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Fig. 3. Illustration of ram load and velocity traces for extrusion with central burst.

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Fig. 4. Micrographs showing the propagation of the defect along the shear discontinuity just after defect initiation. Note that the shear band is more developed ahead of the defect than in the vicinity of the defect.
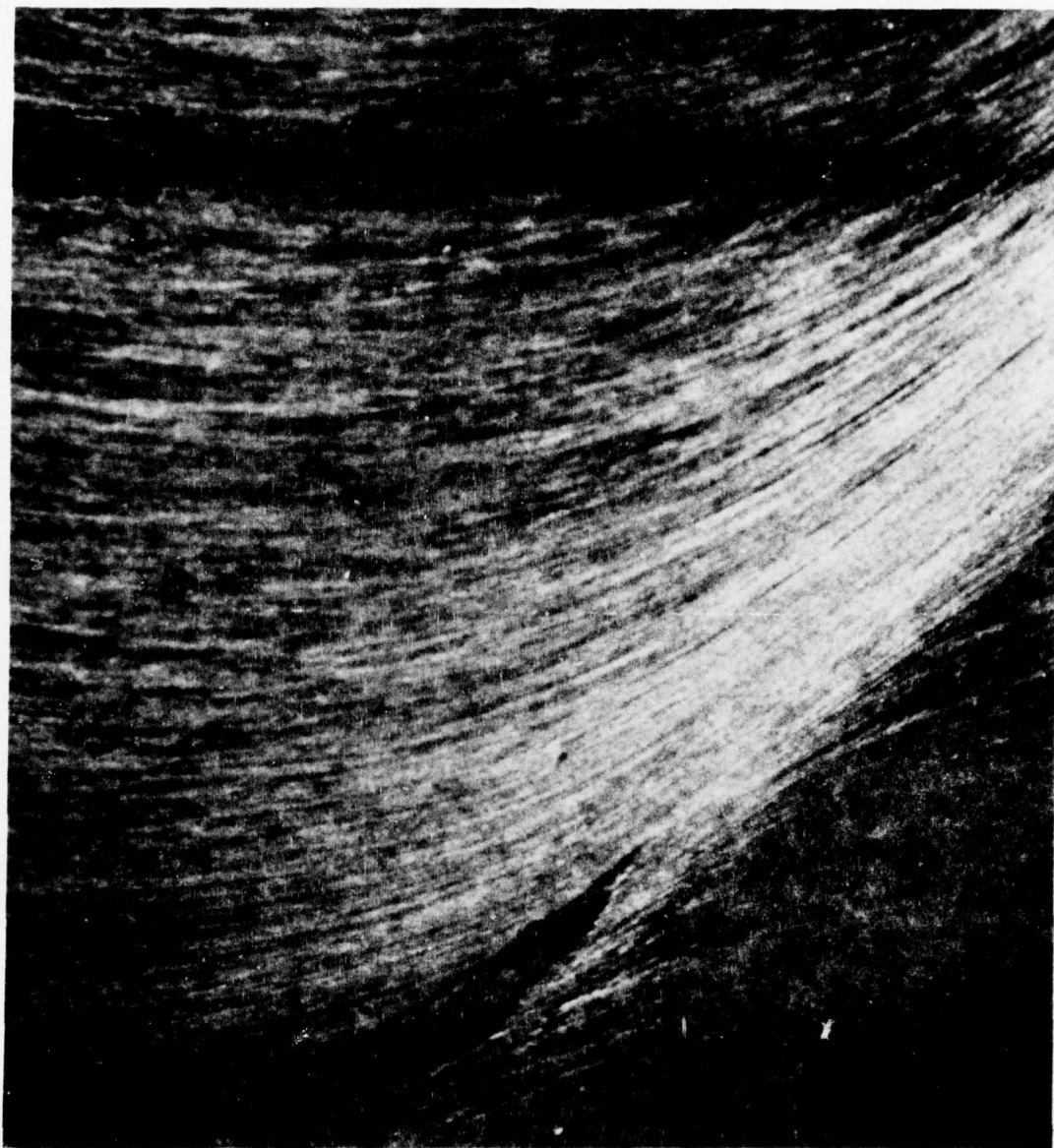
Fig. 5. Micrograph of crack tip when the defect is approximately one-half developed.

Fig. 6. Propagation of the defect at two-thirds development.
Note the blunted tip and sharply defined band of
localized shear.

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Fig. 7. Crack tip as central burst approaches complete
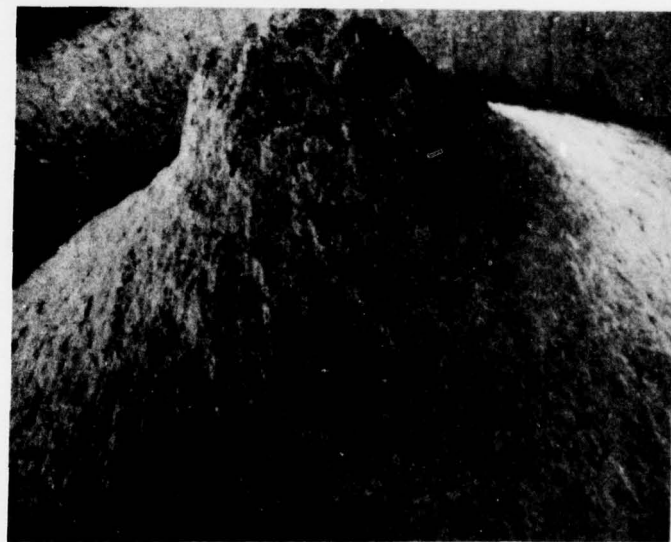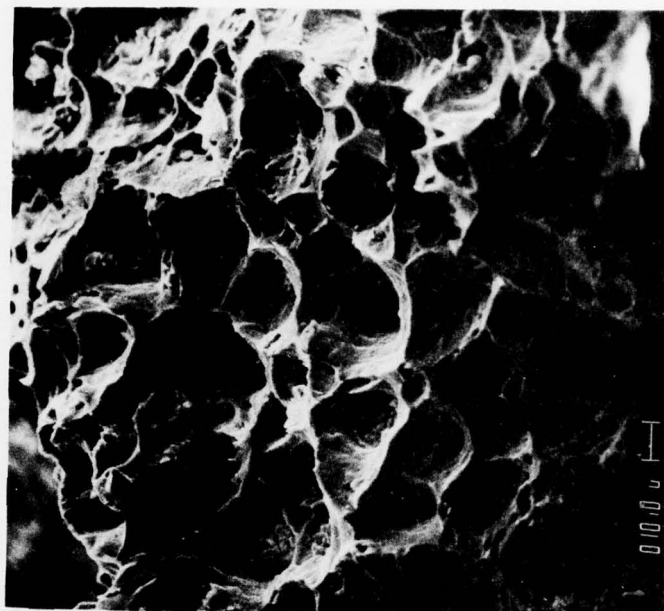   development.

Fig. 9. SEM micrograph of the tip of the central burst cone showing large voids nucleated by inclusions. Fracture is of the ductile rupture type.

Fig. 8. SEM macrograph of central burst cone.

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Fig. 11. SEM fractograph of the shear portion along the wall of the central burst cone.
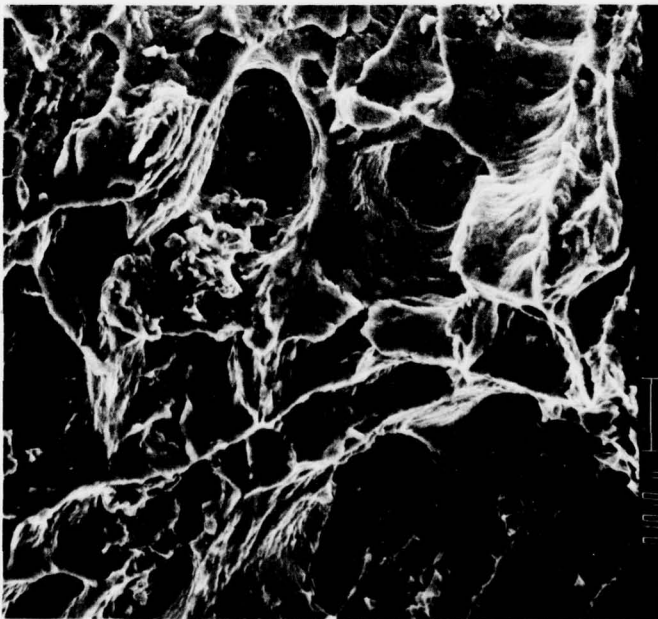

Fig. 10. SEM fractograph of the central burst cone near the tip. Deep voids connected by relatively sharp ridges are evident. Also seen are rippled surfaces of the void walls.
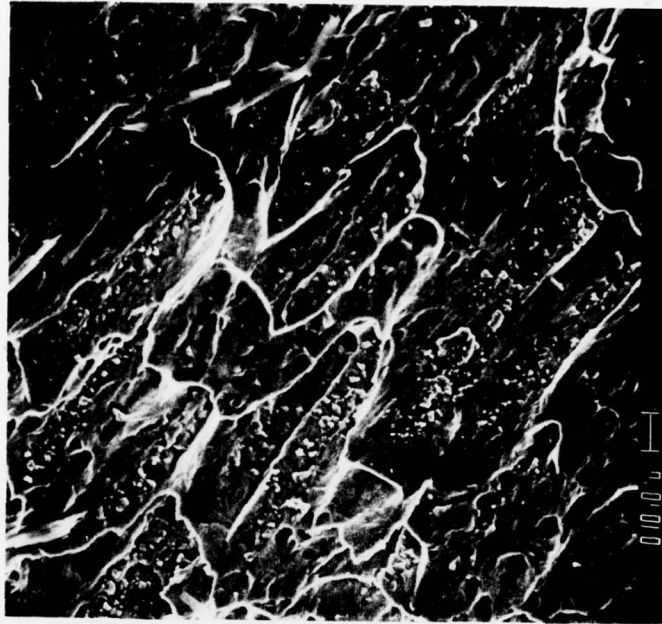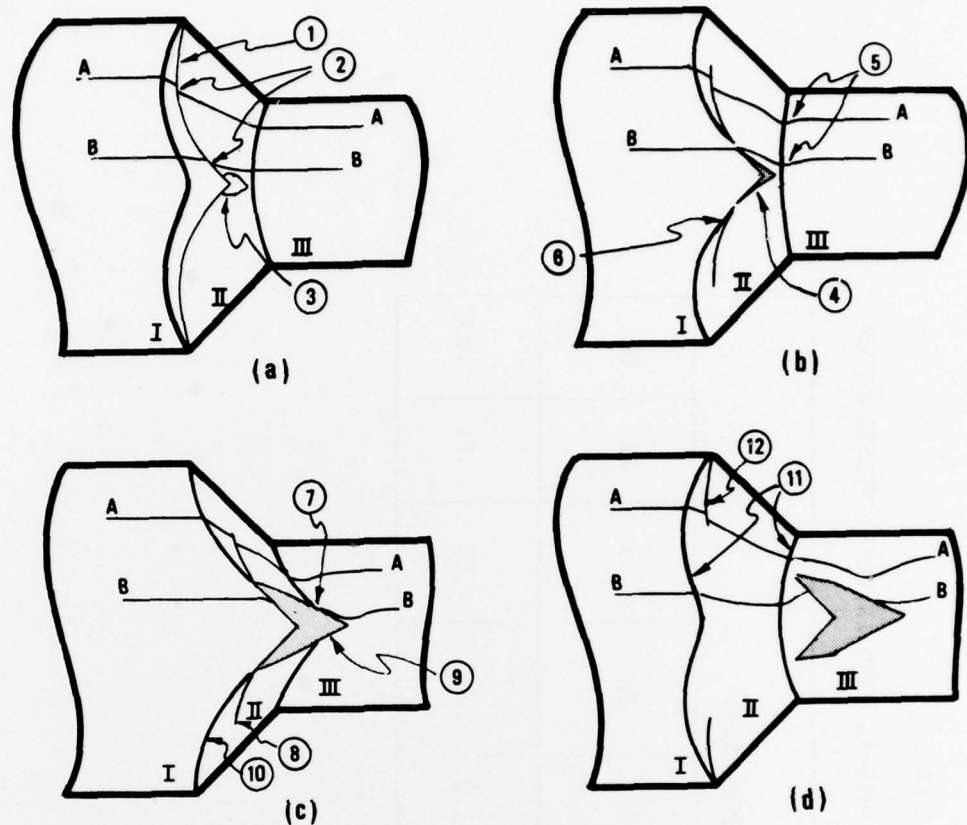
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Region I – Nondeformed Material
Region II – Deformation Zone
Region III – Product Material

Fig. 12. Phenomenological mechanism of the development, propagation and repetition of the central burst defect. a) Development of tangential velocity surfaces (1) occurs with bands of localized flow. Tangential flow along the discontinuity (2) is translated to axial flow toward the die exit and results in a region of enhanced tensile stress (3) at the billet axis. b) Initiation of the central burst defect (4) results from tensile overload. Wavy flow lines (5) develop while the deformation zone volume shrinks by movement of the entrance boundary (6) toward the die exit. c) Discontinuous flow lines develop (7) as the defect propagates along the discontinuity surface but propagation becomes less energetically favorable as the geometric position of the flow surface proceeds through the deformation zone (8). The defect opens rapidly (9) as flow concentrates (10) at the outer flow lines. d) As the defect passes through the die the deformation zone (11) becomes re-established and new tangential velocity discontinuity surfaces (12) begin at the outer surfaces of the billet near the entrance to the die cone.

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TABLE 1

CHEMICAL ANALYSIS OF 7075-AL USED IN THIS INVESTIGATION

COMPOSITION								
	Zn	Mg	Cu	Cr	Fe	Si	Ti	Mn
	5.5	2.2	1.6	1.8	.14	≈.07	.01	.03

TABLE 2

EXTRUSION VARIABLES AND DEFORMATION PRESSURES

Extrusion Number	Die Ratio	Die Angle (degrees)	Die Finish RMS	Preheat Temp. (°F)	Ram Speed (ips)	Pressure Peak/Run (ksi)
6307	4:1	90	32	300	1.8	154/113
6308	4:1	90	32	300	1.8	154/113
6309	4:1	90	32	300	1.8	170/122
6310	4:1	90	32	300	1.7	173/122
6311	4:1	90	32	300	1.8	170/113
6312	4:1	90	32	300	1.7	167/119

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